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ORIGINAL PAPER

Bending moment resistance of dowel corner joints in case-type furniture under diagonal compression load

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Abstract: We investigated bending moment resistance under diagonal compression load of corner doweled joints with plywood members. Joint members were made of 11-ply hardwood plywood of 19 mm thickness. Dowels were fabricated of Beech and Hornbeam species. Their diameters (6, 8 and 10 mm) and depths of penetration (9, 13 and 17 mm) in joint members were chosen variables in our experiment. By increasing the connector's diameter from 6 to 8 mm, the bending moment resistance under diagonal compressive load was increased, while it decreased when the diameter was increased from 8 to 10 mm. The bending moment resistance under diagonal compressive load was increased by increasing the dowel's depth of penetration. Joints made with dowels of Beech had higher resistance than dowels of Hornbeam. Highest resisting moment (45.18 N·m) was recorded for joints assembled with 8 mm Beech dowels penetrating 17 mm into joint members Lowest resisting moment (13.35 N·m) was recorded for joints assembled with 6 mm Hornbeam dowels and penetrating 9 mm into joint members.

Keywords: bending moment resistance, plywood, dowel, diameter, corner joint, case-type furniture

Introduction

The performance of case furniture under external loads depends on the species of lumber and the design of joints used in construction (Tas 2010). Thus, for wood and wood-based panel furniture, proper design of the joints is one of the most important steps in the manufacturing process (Maleki et al. 2012).

One of the most widely used connections in case-type furniture construction is the dowel joint. Dowels are often used as primary connectors in furniture frames constructed of both solid wood and composites, including plywood and oriented stranded board (Eckelman et al. 2003). Where cost is a consideration in furniture assembly, dowel joints can be used instead of other types of furniture joints, including mortise and tenon joints. Because of their low cost and favorable production characteristics, dowel pins have traditionally been a favorite connector in the furniture industry. Dowel pins are also self-aligning and locate parts for further assembly without the use of jigs (Eckelman 2003).

Factors affecting the strength of dowel joints have been investigated in many studies (Eckelman and Haviarova 2007; Eckelman et al. 2002; Erdil and Eckelman 2001; Erdil et al. 2003; Tankut 2005; Zhang and Eckelman 1993a, 1993b and 2003; Zhang et al. 2002a and 2002b).

Zhang and Eckelman (1993a) demonstrated that dowel diameter and depth significantly affect the bending moment resistance of single dowel joints. Erdil et al. (2003) studied withdrawal and bending moment resistance of dowel-nuts in plywood and oriented stranded board. Eckelman and Haviarova (2007) reported that stiffness of the large wooden dowels is nearly proportional to the diameter of the dowels. Increasing dowel diameter and depth of dowel penetration into the face member increases the bending moment resistance of dowel joints (Zhang and Eckelman 1993b). Since furniture joints are subjected to various stresses under external loads, information on strength performance of joints under external loads is needed for proper engineering design of furniture construction. Although many studies of the strength of dowel joints can be found in the scientific literature, limited information is available on the bending performance of dowel joints constructed of plywood members under diagonal compression loads. To address this question we determined the effects of three dowel diameters, three penetration depths, and two dowel wood species on bending moment resistance of L-type dowel joints constructed with plywood members under diagonal compression load.

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Materials and methods

General configuration and dimensions of L-type corner joints used in this study are depicted in Fig. 1. Hardwood plywood was used to construct the joint specimens (Fig. 2) because it is a widely used material in furniture frame construction, primarily as stock material for table, for kitchen cabinet, and for doors and drawers. Using face-milling cutters 6, 8, and 10 mm in diameter, dowel holes were cut in the horizontal and vertical elements of joints. The clearance between the dowel surfaces and hole walls was nominally 0.05 mm. The depth of penetration of the dowel in the face member was nominally 30 mm for all joint specimens, while the dowel penetration depth in the edge member was nominally 9, 13, and 17 mm in such a way that the clearance between the end of the dowel and bottom of the holes was nominalyl 0.125 mm. Beech and hornbeam multi-grooved dowels were used to fabricate the specimens. Density, module of elasticity (MOE), and module of rupture (MOR) values of the two dowel species were measured according to the procedures described in ASTM D-2395 and ASTM D-143 standards (Table 1). Polyvinyl acetate (PVAc) adhesive (1.08 $gr\cdot cm^{-3}$ density and 60% solid content) was applied both to the dowel surfaces and dowel holes, a piece of wax paper was inserted between the face member and the end of the edge member, and the joints were assembled. Five replicates were constructed for each treatment. Joint specimens were clamped for 24 hours while the adhesive layer dried. The specimens were conditioned in a conditioning chamber with a relative humidity of 65%±1% and a temperature of 20°C±2°C to reach equilibrium moisture content (12%) and so the adhesive could achieve its full strength (Altinok et al. 2009). After this period, 90 joint specimens (3 (penetration depth) × 3 (dowel diameter) × 2 (wood species) × 5 (replication)) were tested on a computer-controlled Instron testing machine (4486) using a standard testing set-up (Fig. 3). Rate of loading was 5 $mm\cdot min^{-1}$ during the tests (Altun et al. 2010; Dalvand et al. 2012; Maleki et al. 2012a and 2012b), and the ultimate load was taken as the point of failure.

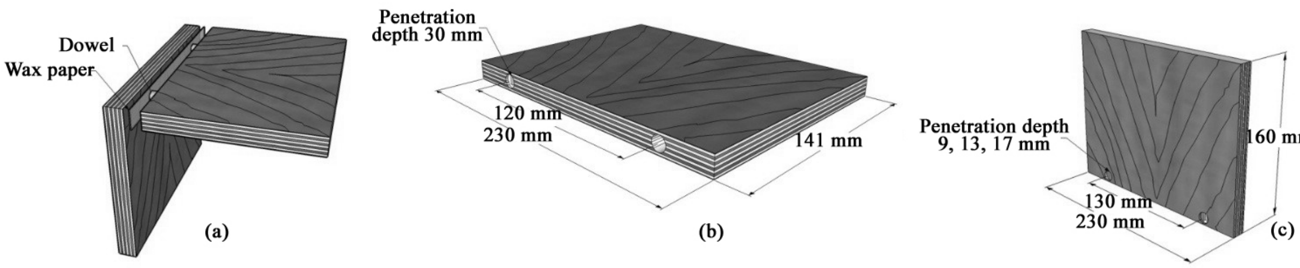

Fig. 1: Configuration and dimensions of joints, a: assembled joint; b: edge member; c: face member.

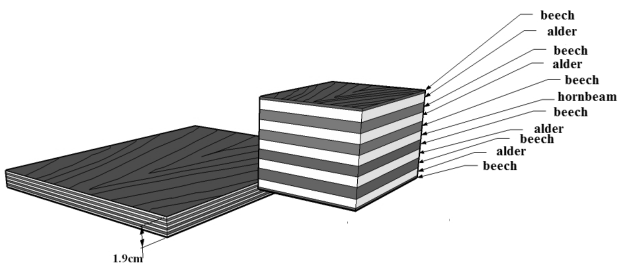

Fig. 2: Hardwood (11 ply) plywood

Ultimate bending moment resistance of joints, M ($N\cdot mm$), was calculated using following equation:

$$M = P_{\max} \times L \tag{1}$$

where, P is the ultimate failure load (N), and L is the moment arm (mm).

Data were analyzed using SPSS software. Analysis of variance (ANOVA) was used to quantify differences between variables. The Duncan test was used assess differences between groups. All comparisons were made at the 5% significance level.

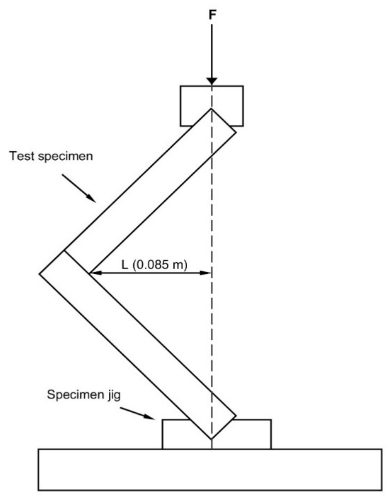

Fig. 3: Testing set-up used to evaluate bending moment resistance of joints

Table 1: Technical properties of dowel

Wood species	Density ($g\cdot cm^{-3}$)	MOE (MPa)	MOR (MPa)
Beech	0.62	11680.67	123.633
Hornbeam	0.71	11215.67	121.7533

Results and discussion

Average values of ultimate bending moment resistance of the joints under diagonal compression load are listed in Table 2. The highest bending moment resistance was recorded for joints constructed with 8 mm diameter beech dowel with 17 mm penetration depth. The lowest bending moment resistance was recorded for joints made with hornbeam dowels 6 mm in diameter and penetrating to 9 mm depth. ANOVA results for bending moment resistance values of tested joints are given in Table 3. Effects of diameter and penetration depth of dowel on bending moment resistance of joints were highly significant at p <0.01. Furthermore, the effect of dowel wood species on the strength of joints was significant at p <5%. With the exception of A × C group, the interactions between bilateral different groups were not statistically significant at p <5%.

Table 2: Average values of ultimate bending moment resistance of joints

Wood species	Penetration depth (mm)	Dowel diameter (mm)	Bending moment capacity (N·m)	Standard deviation
Beech	9	6	19.18	1.26
		8	27.8	3.41
		10	23.6	2.44
	13	6	26.41	4.28
		8	37.91	2.89
		10	32.67	4.20
	17	6	27.98	2.05
		8	45.18	7.19
		10	33.08	4.13
Hornbeam	9	6	13.35	2.75
		8	27.11	2.91
		10	28.91	3.05
	13	6	22.52	2.44
		8	37.12	3.32
		10	32.05	1.78
	17	6	26.85	2.97
		8	36.7	6.83
		10	32.53	6.55

Independent effects of test variables on bending moment resistance of joints under diagonal compression load along with results of the Duncan tests for assessment of differences between groups are listed in Table 4. The bending moment resistance of joints fabricated with beech dowel was approximately 6% higher than for joints constructed with hornbeam dowel. Beech dowel recorded a higher rupture module than hornbeam dowel (Table 4). The species of lumber used for dowels can explain differences in bending moment resistance of joints.

The bending moment resistance of joints generally increased with increasing depth of penetration of dowels. Average bending moment resistance of joints with 17 mm penetration depth was 44% and 7% higher than in joints with 9 and 13 mm penetration depths, respectively. These results are in agreement with those reported by Zhang and Eckelman (1993a) and Eckelman et al. (2002). However, by Duncan test, the change in penetration depth of dowel from 13 mm to 17 mm had no significant effect on bending moment resistance of joints.

Table 3: Results of ANOVA for bending moment resistance of joints

Source	df	Mean square	F	Sig.
Wood species (A)	1	77.429	4.973	0.029
Penetration depth of dowel (B)	2	895.656	57.529	0
Dowel diameter (C)	2	1209.78	77.705	0
A×B	2	16.728	1.074	0.347
A×C	2	59.001	3.79	0.027
B×C	4	31.551	2.027	0.1
A×B×C	4	38.053	2.444	0.054

Table 4: Independent effects of test variables on bending moment resistance of joints

		Bending moment capacity (N·m)	SD[a]	HG[b]
Wood species	Beech	30.42	8.24	
	Hornbeam	28.57	7.95	
Penetration of depth (mm)	9	23.32	6.13	A
	13	31.45	6.33	B
	17	33.72	7.87	B
Dowel diameter (mm)	6	22.71	5.81	A
	8	35.3	7.69	C
	10	30.47	5	B

a: Standard deviation; b: Homogeneity group different letters in a column refer to significant differences among the factors at 0.05 confidence level.

The bending moment resistance of joints is a non-linear function of dowel diameter (Table 4). In this case, the highest bending moment resistance was recorded for joints with 8 mm diameter dowel. The bending moment resistance of joints with 8 mm diameter dowel was approximately 55% and 15% higher than for joints with 6 and 10 mm diameter dowels, respectively. The low bending moment resistance of joints (for 10 mm diameter dowels) was probably due to sudden failure at the edge of panels before the joints could achieve their maximum strength capacity. The increase from 8 to 10 mm in dowel diameter caused reduced thickness of the panel edge. This change caused untimely failure in this part of the panel that was not due to failure of the dowel or the adhesive line (Fig. 4).

For joints with penetration depth of 9 mm, there was no significant difference between dowel species, while the differences between dowel species in joints with 13 and 17 mm penetration depths were statically significant at the 5% level. In this part of the experiments and excepting joints with 9 mm penetration depth, all failures occurred in the dowel pin itself rather than in the adhesive line. However, in the case of joints with 9 mm penetration depth, failure occurred in the adhesive line. Therefore, with increase dowel penetration depth, the bending moment resistance of joints became more a function of the mechanical properties of the wood used to fabricate the dowel pin.

In the case of interaction between dowel species and diameter, the highest bending moment resistance was recorded for joints with 8 mm diameter beech dowel. The lowest bending moment resistance was recorded for joints made with 6 mm diameter

hornbeam dowel. Likewise, bending moment resistances of joints made with 6 and 8 mm diameter beech dowels were higher than those of joints with 6 and 8 mm diameter hornbeam dowels. In the case of 10 mm diameter dowel, there was no significant difference in bending moment resistance of joints made from beech or hornbeam dowels. This was due primarily to joint failure at the edge of panels.

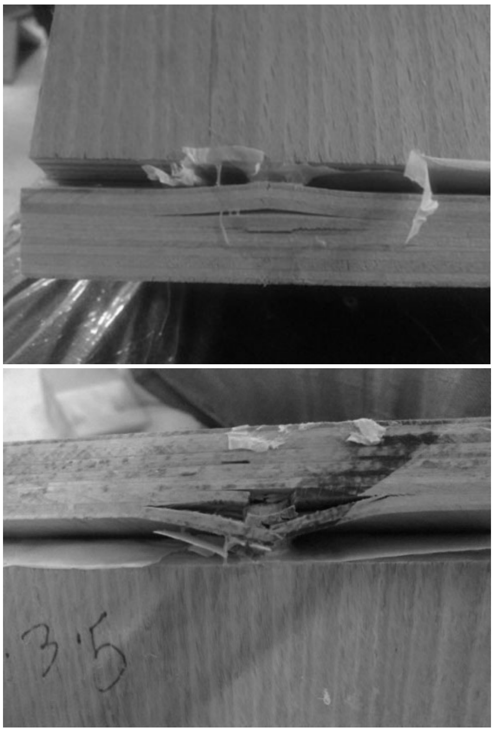

Fig. 4: Failure modes in joints with 10 mm diameter dowel

In the case of interaction between dowel diameter and penetration depth, maximum bending moment resistance was recorded for joints made with 8 mm diameter dowel and 17 mm penetration depth. Least bending resistance was recorded for joints with 6 mm diameter dowels and penetration depth of 9 mm.

Conclusions

The bending moment resistance of joints with beech dowels was, on average, higher than for joints with dowels made of hornbeam. Bending moment resistance of joints increased with increasing penetration depth and diameter of dowels. However, bending moment resistance of joints decreased with increasing dowel diameter from 8 to 10 mm. This unusual phenomenon was probably due to the reduced edge thickness of panels caused by the larger dowel diameter. As a result, the failure occurred in this area before the joint achieved its maximum strength. Maximum bending strength was recorded when joint failure occurred in the dowel pins rather than in the adhesive line or edge of panels.

Although the effects of various parameters, such as dowel or joint dimensions, on the strength of furniture joints are generally known by manufacturers, there are optimal ranges for each parameter. For example, in the case of dowel diameter, it is probably predictable that joint strength increases with increasing dowel diameter. Our results showed, however, that the optimum dowel diameter was 8 mm and the increase in diameter from 8 to 10 mm caused reduced joint strength. Therefore, researchers can provide a range of optimum values for parameters affecting furniture joint strength and this could be helpful for engineering design of furniture structures.

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